

6.0 Summary and Implications

6.1 Introduction

This study was conducted as part of a National Assessment effort aimed at evaluating the impacts of climate change and climate variability on the United States across its various regions and including sectors beyond agriculture. We set out to understand the potential implications of climate change for agriculture. Chapter 1 provided an overview of the goals of the assessment and a broad brush portrait of forces shaping US agriculture over the past 100 years, where US agriculture finds itself today, and some of the major forces that will shape agriculture into the next century. Chapter 2 reviewed previous studies on the impacts of climate change on agriculture including identification of some of the key findings, how the literature has developed, and where some of the major gaps remain.

The substantive new work of the agriculture sector assessment was reported in chapters 3 through 5. Chapter 3 considered the impacts of the future climate change on production agriculture and the US economy. It reported a series of crop modeling studies that examined in detail the impacts of climate change on crop yield with the intent of providing a representative estimate of climate impacts on US crop yields under 2 climate scenarios for climates projected to represent the decade of the 2030s and the 2090s. These results were then combined with estimates of changes in water supply, pesticide expenditures, livestock, and international trade due to climate change to understand the combined impacts on the US agricultural economy, resource use, and the distribution of impacts in the US by producer and consumer and by region.

Chapter 4 considered the question of climate variability and extreme events, the chance that climate change may cause the probability of extreme events to change, and the potential consequences for agriculture. Climate variability, yield variability and how farmers cope with variability apart from climate change is the subject of many books. Crop insurance, futures markets, weather derivatives, and technological options such as irrigation, storage facilities, and shelter for livestock are intricate parts of the agricultural system because of weather variability. We, in no way, have covered this broad literature but have tried to understand the extent to which climate change could exacerbate or reduce variability.

The subject of Chapter 5 was one of the poorly researched areas of climate impacts on agriculture, the arena of environment and resource implications. Soil erosion, the fate of chemical residuals, and the quality and quantity of soil and water resources are highly dependent on climatic conditions. Chapter 5 began the process of examining some of these interactions. The approach we used in this chapter was to focus on some case studies to illustrate the issues and problems that could arise as we try to manage resource use and agriculture's relationship with the environment under a changing climate. We

1 examined the Chesapeake Bay drainage area that extends through Maryland, Delaware
2 and Pennsylvania, the San Antonio Texas area where the Edward's Aquifer provides
3 most of the water supply, pesticide use and its relationship to climate, and the direct
4 impact of climate on soil. This list leaves many problems unexplored, including such
5 issues as soil erosion, the potential for climate to change the level of pollutants such as
6 ozone that are detrimental to crops, the interaction of agriculture with wildlife habitat,
7 livestock waste issues, and many others.

8 One of the goals of the assessment was to respond directly to questions
9 stakeholders felt were important. There remains a considerable gap between the
10 questions of the stakeholder community with whom we interacted and the answers we
11 were able to provide. To answer many of these questions requires a modeling capability
12 and precision that we do not possess. The most fundamentally difficult conceptual
13 problem is to represent completely the dynamics of social, economic, and physical
14 interactions in their full complexity. If we could know and model these dynamics then
15 we could answer questions such as when will climate change begin to affect the
16 agricultural sector, when will it be noticed, by who, and how will they react to it? As
17 individuals, organizations, and local governments react, or not, how will it change the
18 relative economic position of one farm versus another or one region versus another?
19 Almost any change provides an opportunity for those who are prepared for it and adjust
20 early and a threat for those who fail to adjust. Technical change, a force that generally
21 improves economic performance, creates losers along with winners. Pollution regulation,
22 while usually seen as increasing the cost of production in the industries targeted, can
23 create winners among those companies that have or can create innovative solutions to
24 meet the environmental regulation, thus allowing them to win market share against their
25 slower to respond rivals. Whether climate change generally improves agricultural
26 productivity in the US as projected in the scenarios we investigated or leads to losses in
27 productivity as has been projected by some previous forecasts, there will be winners and
28 losers.

29 In this final Chapter we review the principal findings and try to draw out the
30 implications of these findings for adaptation and adjustment. We make only a small start
31 in this direction. In this regard, the research and assessment team we assembled for the
32 task of assessing climate impacts on agriculture was best suited to describing the impacts
33 of climate change. To understand what to do requires a far more detailed engagement of
34 those who are directly involved—the farmers, legislators, research managers, government
35 program managers, and the local communities who will be affected and who are the one's
36 whose incomes, livelihoods, and jobs are on the line. This report is, thus, a start at that
37 process from the side of a team of researchers.

38 39 **6.2 Summary of Findings**

40
41 The new quantitative work we undertook confirmed in many ways the broad results of
42 previous studies:

- 1
2 • *Over the next 100 years and probably beyond, human-induced climate change as*
3 *currently modeled is unlikely to seriously imperil aggregate food and fiber*
4 *production in the US, nor will it greatly increase the aggregate cost of agricultural*
5 *production.* Our quantitative results based on newer climate scenarios and including
6 a broader range of impacts including changes in water resource, pesticide
7 expenditures, and livestock confirm the emerging consensus findings in the literature
8 and, if anything, suggest significantly more positive results than previous studies.
9
- 10 • *There are likely to be strong regional production effects within the US with some*
11 *areas suffering significant loss of comparative advantage (if not absolutely) to other*
12 *regions of the country.* In the scenarios we evaluated the Lake states, Mountain states
13 and Pacific region showed gains in production while the Southeast, the Delta,
14 Southern Plains and Appalachia generally lost. Results in the Corn Belt were
15 generally positive. Results in other regions were mixed depending on the climate
16 scenario and time period. The regional results show broadly that climate change
17 favors northern areas and can worsen conditions in southern areas, a result shown by
18 many previous studies.
19
- 20 • *Global market effects can have important implications for the economic impacts of*
21 *climate change.* The position of the US in the world agricultural economy, being
22 both a significant food consumer and exporter, means that changes in production
23 outside the US lead to consumer benefits from lower prices roughly balancing
24 producer losses. The situation is reversed if global production changes cause world
25 prices to rise. As a result, the net effect on the US economy did not change much
26 under different global impact assumptions. The main effect was to change the
27 distribution of impacts among producers and consumers. We were unable to conduct
28 a new assessment of impacts on the rest of the world. Trade scenarios drawn from
29 previous work showed both small increases and decreases in world prices.
30
- 31 • *Effects on producers and consumers often are in opposite directions and this is often*
32 *responsible for the small net effect on the economy.* In the Canadian Center climate
33 scenario the absolute effects on producers and consumers were nearly balanced. In
34 relative terms, the 4 to 5 billion dollar losses to producers in the CC scenario
35 represent 13 to 17 percent loss of income whereas the gains of 12 to 14 billion dollars
36 to consumers in the HC scenarios represent only a 1.1 to 1.3 percent gain to
37 consumers. While these losses to producers are substantial, to place this in context, a
38 good comparison is historical changes in land values, the asset that would ultimately
39 be affected by changes in climate. Between 1980 and 1983, US agricultural land
40 values fell on the order of 50 percent. The projected losses due to climate change are
41 projected over the course of 3 to 4 decades or more and would thus likely inflict far
42 less adjustment costs.
43
- 44 • *US agriculture is a competitive, adaptive, and responsive industry and will adapt to*
45 *climate change; all assessments reviewed above have factored adaptation into the*

1 *assessment*. Adaptation improved results substantially under the Canadian center
2 climate scenario but much less so under the Hadley center scenario where climate
3 change was quite beneficial to productivity without adaptation.

- 4
- 5 • *The agriculture and resource policy environment can affect adaptation*. These
6 conclusions are based primarily on our review of the literature. We did not
7 extensively consider the policy environment and its impact on adaptation in the new
8 work we conducted. Among the policies to consider are water markets, agricultural
9 commodity programs, crop insurance, and disaster assistance.

10
11
12 Several limitations have been present in past assessments. We addressed some of the
13 most serious of these limitations:

- 14
- 15 • We used more realistic “transient” climate scenarios that simulated gradual climate
16 change as a result of gradually increased atmospheric CO₂ and included the cooling
17 effect of sulfate aerosols.
 - 18
 - 19 • We used site-level crop model results combined with a spatial equilibrium economic
20 model to generate national and regional results that included more than a dozen crops.
21 We compared this approach with other approaches that had less crop detail but had
22 other strengths. We investigated trade links and implications using sensitivity
23 analysis based on previous estimates of impacts around the world.
 - 24
 - 25 • We examined scenarios of change in variability and implications for the agricultural
26 economy as well as the extent to which climate is a factor in existing variability in
27 crop yields.
 - 28
 - 29 • We considered a more complete interaction of effects such as changes in water
30 resources and pesticide expenditures.
 - 31
 - 32 • We conducted case studies of environmental-agricultural interactions to examine the
33 potential effects of climate change on the Chesapeake Bay drainage area and of
34 ground water use in the Edwards aquifer area.

35
36 The most important changes in this study of the effects of climate change on production
37 agriculture are the direct effects on crop yields. We conducted crop simulations studies
38 at 45 sites across the US that were selected to be representative of the major production
39 regions and areas that potentially could be important under climate change. We also
40 compared these results to a more limited investigation using a model that estimated yields
41 at over 300 representative sites using a simpler crop modeling methodology. The specific
42 results we found based on the two climate scenarios we investigated include:

- 43
- 44 • Effects on crop yields varied by climate scenario and site, but overall were far more
45 positive than for many previous studies.

- 1 • **Winter wheat.** Yields increased 10-20% under Hadley, but decreased by more
2 than 30% under the Canadian Center climate and yields were more variable under
3 the Canadian climate scenario. Adaptation helped to counterbalance yield losses
4 in the Northern Plains but not in the Southern Plains. Irrigated wheat production
5 increased under all scenarios by 5-10% on average.
- 6 • **Spring wheat.** Yields increased by 10 to 20 percent in 2030 under both climate
7 scenarios. Under the Hadley climate scenario yields generally increased up to 45
8 percent higher by 2090, but under the Canadian Center scenario yields in 2090
9 showed declines of up to 24 percent. Irrigated yields were negatively affected by
10 higher temperatures. Adaptation techniques, including early planting and new
11 cultivars, helped to improve yields under all scenarios.
- 12 • **Corn.** Dryland corn production increased at most sites, due to increases in
13 precipitation under both climate scenarios. Larger yield gains were simulated in
14 the northern Great Plains and in the northern Lake State region, where warmer
15 temperatures were also beneficial to production. Irrigated corn production was
16 negatively affected at most sites.
- 17 • **Potato.** Irrigated potato yields generally fell, and quite substantially at some sites
18 by 2090, while, under rainfed conditions, yield changes were generally positive.
19 Adaptation of planting dates mitigated only some of the predicted losses. There
20 was little room for cultivar adaptation, because the predicted warmer fall and
21 winter temperatures negatively affected tuber formation.
- 22 • **Citrus.** Yields largely benefited from the warmer temperatures predicted under all
23 scenarios. Simulated fruit yield increased in the range of 20-50%, while irrigation
24 water use decreased. Crop losses due to freezing diminished by 65% in 2030, and
25 by 80% in 2090.
- 26 • **Soybean.** Soybean yields increased at most sites analyzed, in the range 10 to 20%
27 for sites of current major production. Larger gains were simulated at northern
28 sites where cold temperatures currently limit crop growth. The Southeast sites
29 considered in this study experienced significant reductions under the Canadian
30 climate scenario. Losses were reduced by adaptation techniques involving the use
31 of cultivars with different maturity classes.
- 32 • **Sorghum.** Sorghum yields generally increased under rainfed conditions, in the
33 range 10-20%, due to the increased precipitation predicted under the two
34 scenarios considered. Warmer temperatures at northern sites further increased
35 rainfed grain yields. By contrast, irrigated production was reduced almost
36 everywhere, because of negative effects of warmer temperatures on crop
37 development and yield.
- 38 • **Rice.** Rice yields under the Hadley climate change scenario increased in the range
39 1-10%. Under the Canadian climate scenario, rice production was 10-20% lower
40 than current levels at sites in California and in the Delta region.
- 41 • **Tomato.** Under irrigated production, the climate change scenarios generated yield
42 decreases at Southern sites and increases at Northern sites. These differential
43 regional effects were amplified under the Canadian Center scenario as compared
44 with the Hadley center scenario.

- 1 • The factors behind these more positive results varied but can generally be traced to
2 aspects of the climate scenarios.
3
- 4 • Increased precipitation in these transient climate scenarios is an important factor
5 contributing to the more positive effects for dryland crops and explains the
6 difference between dryland and irrigated crop results. The benefits of increased
7 precipitation outweighed the negative effects of warmer temperatures for dryland
8 crops whereas increased precipitation had little yield benefits for irrigated crops
9 because water stress is not a concern for crops already irrigated.
10
- 11 • The coincidence of geographic pattern of precipitation and crop production
12 contributed to differences among crops. Crops grown in the Great Plains where
13 drier conditions were projected, at least under the Canadian center model, and
14 crops grown in the Southern portion of the country, already sometimes suffering
15 heat stress, were more negatively affected. Heat-loving crops like citrus benefited
16 while crops that do well under cool conditions such as potatoes suffered.
17
- 18 • Another factor behind the more positive results is that previous studies have been
19 based on 2x CO₂ equilibrium climate scenarios with larger temperature increases
20 than exhibited by these transient scenarios through 2100.
21
- 22 • The crop models and crop modeling approaches were substantially the same as in
23 previous studies.
24
25

26 The crop results were combined with impacts on water supply, livestock, pesticide use,
27 and shifts in international production to estimate impacts on the US economy. This
28 allowed the estimation of regional production shifts and resource use in response to
29 changing relative comparative advantage among crops and producing regions.
30

- 31 • The net economic effect on the US economy was generally positive reflecting the
32 generally positive yield effects. The exceptions were simulations under the Canadian
33 climate scenario in 2030, particularly in the absence of adaptation. Foreign
34 consumers gained in all the scenarios as a result of lower prices for US export
35 commodities. The total effects (net effect on US producers and consumers plus
36 foreign gains) were on the order of a \$1 billion loss to \$14 billion gain.
37
- 38 • Producers' incomes generally fell due to lower prices. Producer losses ranged from
39 about \$0.1 up to \$5 billion. The largest losses were under the Canadian Center
40 climate. Under the Hadley center climate producers lost from lower prices but
41 enjoyed considerable increase in exports such that the net effect was for only very
42 small losses.
43
- 44 • Economic gains accrued to consumers through lower prices in all scenarios. Gains to
45 consumers ranged from \$2.5 to \$13 billion.

- Different scenarios of the effect of climate change on agriculture abroad did not change the net impact on the US very much but redistributed changes between producers and consumers. The direction depended on the direction of effect on world prices. Lower prices increased producer losses and added to consumer benefits. Higher prices reduced producer losses and consumer benefits.
 - Livestock production and prices are mixed. Increased temperatures directly reduce productivity but improvements in pasture and grazing and reductions in feed prices due to lower crop prices counter these losses.
- In terms of improving the coverage of potential impacts of climate change on agriculture we made significant advances over previous assessments. One set of our advances involved coverage of resource and environmental effects.
- Agriculture's demand for water resources declined nationwide on the order of 5 to 10 percent in 2030 and 30 to 40 percent in 2090. Land under irrigation showed similar magnitudes of decline. The crop yield studies in general favored rainfed over irrigated production and showed declines of water demand on irrigated land.
 - Agriculture's pressure on land resources generally decreased. Area in cropland decreased 5 to 10 percent, area in pasture decreased 10 to 15 percent. Animal unit months (AUMs) of grazing on western lands decreased on the order of 10 percent in the Canadian climate scenario and increased 5 to 10 percent under the Hadley climate scenario.
 - The Chesapeake Bay is one of nation's most valuable natural resources but has been severely degraded in recent decades. Soil erosion and nutrient runoff from crop and livestock production have played a major role in the decline of the Bay.
 - Potential effects of climate change on water quality in the Chesapeake Bay must be considered very uncertain because current climate models don't adequately represent extreme weather events such as floods or heavy downpours, which can wash large amounts of fertilizers, pesticides, and animal manure into surface waters.
 - In our simulations we found that under the two 2030 climate scenarios nitrogen loading from corn production increased by 17 to 31 percent compared with current climate. Changes in farm practices by then could reduce loadings by about 75 percent from current levels under today's climate or under either of the climate scenarios.
 - The Edwards aquifer area is another region of the country where agriculture and resource interactions are critical. Agriculture uses of water compete with urban and

1 industrial uses and tight economic management is necessary to avoid unsustainable
2 use of the resource. We find:

- 3
- 4 • Climatic change causes a slightly negative welfare result in the San
5 Antonio region as a whole but has a strong impact on the agricultural
6 sector. The regional welfare loss, most of which is incurred by agricultural
7 producers, was estimated to be between 2.2 -6.8 million dollars per year if
8 current pumping limits are maintained.
- 9
- 10 • A major reason for the current pumping limits is to preserve springflows
11 that are critical to the habitat of local endangered species. If springflows
12 are to be maintained at the currently desired level to protect endangered
13 species, we estimated that under the two climate scenarios pumping would
14 need to be reduced by 10 to 20% below the limit currently set at an
15 additional cost of 0.5 to 2 million dollars per year.
- 16
- 17
- 18 • Welfare in the non-agricultural sector is only marginally reduced by the
19 climatic change simulated by the two climate scenarios. The value of
20 water permits rises dramatically.
- 21
- 22 • Agricultural water usage declines as a result of competition from the non-
23 agricultural sector while nonagricultural water use increases.
- 24
- 25
- 26 • Soil organic carbon may be reduced because warming speeds up decomposition of
27 organic matter, however, increased yields predicted in many areas may counter this if
28 residue is incorporated into soils. Changes in soils due to climate change are unlikely
29 to have significant effects on crop productivity.
- 30
- 31 • Microbial activity in soils is diverse and thus likely resilient to changes in
32 climate.
- 33
- 34 • Poor soils in Canada limit the extent of movement of cropping into these
35 areas.
- 36
- 37 • Soils managed using sustainable production practices, such as reduced
38 tillage and retaining residues on the soil, produce more under either
39 drought or excessively wet conditions and therefore could be a viable
40 adaptation measure if weather becomes more variable.
- 41
- 42 • Pesticide expenditures were projected to increase under the climate scenarios we
43 considered for most crops and in most states we considered.
- 44

- Increases on corn were generally in the range of 10 to 20 percent, on potatoes of 5 to 15 percent and on soybeans and cotton of 2 to 5 percent. The results for wheat varied widely by state and climate scenario showing changes ranging from approximately -15 to +15 percent.
- The increase in pesticide expenditures could increase environmental problems associated with pesticide use but much depends on how pest control evolves over the next several decades. Pests develop resistance to control methods requiring a continual evolution in the chemicals and control methods used.
- The increase in pesticide expenditures results in slightly poorer overall economic performance but this effect is quite small because pesticide expenditures are a relatively small share of production costs.
- The approach we used did not consider increased crop losses due to pests, implicitly assuming that all additional losses were eliminated through increased pest control measures. This may underestimate pest losses.

Another substantial additional contribution of this assessment was to consider the potential effects of climate variability on agriculture.

- A major source of weather variability is the ENSO (El Nino Southern Oscillation) phenomenon. ENSO phases are triggered by the movement of warm surface water eastward across the Pacific Ocean toward the coast of South America and its retreat back across the Pacific, in an oscillating fashion with a varying periodicity.
 - Better prediction of these events would allow farmers to plan ahead, planting different crops and at different times. The value of improved forecasts of ENSO events has been estimated at approximately \$500 million.
 - ENSO can vary intensity from one event to the next, thus, prediction, particularly of the details, of ENSO driven weather are not perfect.
 - There are widely varying effects of ENSO across the country. The temperature and precipitation effects are not the same in all regions, in some regions the ENSO signal is relatively strong while others it is weak, and the changes in weather have different implications for agriculture in different regions because climate-related productivity constraints differ among regions under neutral climate conditions.
 - While highly controversial, at least one recent study projected changes in ENSO as a result of global warming. We simulated the potential impacts of this on agriculture and found:

- An increase in frequency of ENSO could cause a loss equal to about 0.8 to 2.0 percent of net farm income.
- An increase in frequency and intensity could cause a loss of 2.5 to 5.0 percent of net farm income.
- There are differential effects on domestic producers, foreign economies and domestic consumers. We find gains to domestic consumers from increased ENSO frequency and intensity but losses to domestic producers and to foreign economies.
- In general, climate variability is responsible for significant losses in agriculture. Droughts, floods, extreme heat, and frosts can damage crops or cause a complete loss of the crop for the year. Sequential years of crop loss can seriously affect the viability of a farm enterprise.
 - Climate models do not predict extreme events and changes in variability well, making it difficult to produce meaningful estimates of impacts.
 - There are also limits to the ability of crop models to predict the effects of climate variability as yields can depend on very specific aspects of climate including for examples, how many days in a row of high temperatures are experienced, or whether the crop has been subject to gradual hardening against cold temperatures.
 - Changes in mean conditions can affect the variability of crop yields. We conducted a statistical analysis of the impact of changes in mean conditions of crop yield variability for several crops. The results were mixed:
 - For corn and cotton and under the climate scenarios we used yield variability decreased largely due to the increase in precipitation.
 - Wheat yield variability tends to decrease under the Hadley Center climate and increase under the Canadian climate model.
 - Soybean yield variability shows a uniform increase with the Hadley Climate Change Scenario.

6.3 A Resilient and Adaptable Agriculture

The ultimate question for US agriculture over the next several decades is “Can agriculture become more resilient and adaptable given the many forces that will reshape the sector, of which climate change is only one?” US agriculture has, in fact, proved to

1 be very adaptable and resilient along many dimensions but, to stay ahead in a competitive
2 world, we can always ask: “Can it do still better?” For the individual farmer, agribusiness
3 companies, agronomist, or farm-dependent community, it will not matter whether prices
4 are low because of climate change or because of technological change. Granted, a
5 changed climate in a locality has somewhat different implications than a market collapse
6 in Asia or sudden unforeseen demand because of an agricultural production failure in
7 Russia. But ultimately, all of these represent a change in the relative economic
8 conditions across regions. These other types of events and forces create both short-term
9 variability and shape long-term trends. They present changed conditions that are
10 potential opportunities for those that act quickly (and in the right direction) and threats to
11 those who are slow to respond. There, of course, can be real losses and real gains to
12 different regions, which for climate change we have tried to illustrate in this assessment.
13 The challenge for adaptation is to do as well as possible with what the world presents.
14 Limiting climate change is another option for avoiding negative impacts involved with
15 climate change but that issue involves much more than what happens to US Agriculture.

16
17 It is clear that we cannot now predict climate change precisely nor can we predict
18 technology or economic growth around the world decades ahead. It is therefore
19 worthwhile to step back from specific numerical forecasts and consider some of the
20 major forces likely to shape agriculture, describing as best we can the broad directions of
21 these changes, take lessons from what we have learned in agricultural policy from the last
22 half-century or so, describe some of the broad challenges for agricultural policy over the
23 next several decades, and try to fit what we have discovered about climate change into
24 the broader context of agriculture policy over the next several decades.

25
26 Over the past half-century Federal farm policy has aimed to boost farm and rural
27 incomes, smooth out the ups and downs of commodity prices, insure farmers against the
28 inevitable disasters of droughts and floods, feed the poor, improve productivity, protect
29 natural resources, and come to the aid of the small farmer. There were great
30 successes—since 1950 US agricultural productivity doubled, real world food prices fell
31 by two-thirds making it cheaper to feed the world, and the average US farm household is
32 now wealthier than the average nonfarm household. There were also contradictory and
33 costly policies such as supply control with production-based payments and
34 "conservation" programs that idled land with only minimal environmental benefits.

35
36 At the brink of a new century, there is a need to be realistic about the inevitable market
37 and global forces that are simply too powerful to change and avoid the policy pitfalls of
38 the last half-century. As our assessment shows there is at least as good a chance, perhaps
39 a better chance, that climate change will increase agricultural productivity in the US as
40 decrease it. Although we find improved productivity good for US consumers, it
41 generally reduces income and wealth among farmers and agricultural landholders.

1 What are the trends that will shape agriculture, of which climate change is only one, and
2 how can Federal farm policy make US agriculture resilient and adaptable given that we
3 cannot precisely predict any of them?

4
5 The inevitable forces, drawn from our discussions with stakeholders:

- 6
7 • Biotechnology and information technology will revolutionize agriculture over the
8 next few decades. Productivity will increase; prices will fall. Even if these changes
9 are no more powerful than those of the last half-century, we may see geographic
10 shifts of 50 or 100 miles in where crops are produced. The US is well-positioned to
11 lead in developing new technology but many individual (less successful) farmers will
12 be left behind. Moreover, the private sector firms that develop this technology have a
13 strong incentive to market it internationally to capture fully the economic rents
14 associated with its development. Technology development and distribution is
15 becoming internationalized, the economic rents going to the developers of the
16 technology rather than the commodity producers.
17
- 18 • Trade policy, trade disputes (as over genetically modified organisms), and the
19 development of intellectual property rights (or not) across the world will have strong
20 effects on how international agriculture and the pattern of trade develops. There will
21 be constant pressure on profit margins—only those with exceptional managerial
22 expertise and who are able to draw on significant resources will survive in bulk
23 commodity production.
24
- 25 • The industrialization of agriculture will transcend national boundaries, integrating
26 producers, processors, and suppliers to produce uniform product and assure supply.
27 There will be ever fewer farms producing an ever-greater share of production.
28 Despite the resistance of many in the current generation of mid-size farmers,
29 production under contract with processors, vertical integration, and other forms of
30 market organization will dominate most of agriculture. This has already occurred in
31 fruits and vegetables, poultry, and increasingly in pork and beef production.
32
- 33 • The trends in bulk commodity production have given rise to a popular view that niche
34 markets and production for local markets can offer refuge for the family farm.
35 Biotechnology offers the ability to introduce genetic modifications so that crops and
36 livestock can produce pharmaceuticals or produce other designer products. In many
37 ways, these markets are likely to be no less demanding than bulk commodity
38 production. By definition they are small markets and therefore no one product can
39 preserve all family farms. Success will breed competition, driving profits down.
40 Creating markets for new, unique goods will require far more marketing skill than
41 choosing when to sell a bulk commodity like corn or wheat. Success will thus
42 demand many new business skills on how to develop and maintain markets.
43

- Concern about environmental performance of agriculture will continue to grow. How to capitalize on and create incentives to reduce pollution and reap the benefits of agricultural greenspace and landscapes will be the challenge.

This set of challenges suggests several broad responses:

- Make research work for agriculture. Successful adaptation to climate change will require successful R&D. Traditional public R&D is part of the research portfolio but the engine of invention is now in private firms. Basic research remains the province of the public sector. The important element for the future is how to encourage and direct the power of the private research engine to improve environmental performance. Science-based environmental targets implemented with market-based mechanisms can provide sound incentives for innovations that improve environmental performance. Designing market-based mechanisms to deal with non-point pollution has proved difficult, but more attention is needed to assure that whatever mechanisms are chosen, they provide incentives for the private sector to develop and commercialize agricultural technologies and practices with improved environmental performance.
- A world of change, whether from climate or from other forces, will be a world of dislocation for some. The lesson from the last 50 years of agricultural policy is that use of broad based commodity policy to fight rural poverty is an extremely blunt instrument. These payments often end up disproportionately in the hands of the wealthiest farmers. Fifty years ago when the farm population was much poorer than the general population, the regressive aspects of these policies were minimal but that is no longer true today. The goal must therefore be to target income assistance far more carefully to the disadvantaged in the rural areas, many of whom are not actually farmers on any significant scale. Tying aid to the business of farming also tends to merely inflate the value of assets (mainly land) tied to farming. Ultimately, the next generation of farmers pay a higher price for the land and face a higher cost structure than if the payments had not been in place. This sets the stage for another income crisis when the inevitable commodity price variability leads to a downturn in prices. The 1996 farm legislation got rid of most of these elements, replacing them with payments that were ultimately to be phased out after 7 years. Farm sector euphoria over the program when prices were high turned to disenchantment when prices fell. This disenchantment risks a drift back to programs that pay people to produce product that depresses prices, forcing government to buy it up to prop up prices, dump stocks on the market and depress prices, and pay people not to produce.
- Climate variability and the potential for it to increase necessarily focuses attention on risk management strategies. Contract production, vertical integration, forward markets, private savings, household employment decisions, and weather derivatives are market responses to risk. These are likely to evolve further and farmers that are not adept at using them will need to become so. Farmers can adopt technological

1 solutions to risk such as irrigation as insurance against drought, or shorter maturing
2 varieties against frost. However, if adopted primarily to reduce variability in income
3 these strategies can increase costs and make the farm uncompetitive with other farms
4 that have accepted the risk and pooled income variability through savings, contract
5 production, or other market mechanisms. Crop insurance is also such a response for
6 which the Federal government now takes some responsibility. Federal crop
7 insurance contains a devilish public policy dilemma. One aspect of insurance is what
8 is known in economics as “moral hazard.” The existence of insurance reduces the
9 incentive to undertake technological solutions to risks. A second is that under a pure
10 insurance program the enrollee pays insurance each year but over a number of years
11 should expect to get back in loss payments no more than (s)he paid. If (s)he can
12 expect more, then the insurance program is also a subsidy program. This may involve
13 cross-subsidization among enrollees but the subsidizers then tend to drop out or,
14 where Federally managed, the entire program can run a deficit with tax dollar
15 support. There is a risk, then, that the desire to create a Federal insurance program
16 that enrolls a large proportion of farmers will end up as largely a subsidy program. If
17 climate change causes a drift toward more frequent disasters in an area, the premiums
18 for farmers in the area would need to be adjusted upward to maintain the program as a
19 pure insurance program. Failure to adjust premiums could mean, ultimately, that
20 insurance is paying out almost every year. It would, however, be difficult for a
21 Federal program to raise premiums substantially on those areas that have just suffered
22 repeated disaster years. Ultimately, crop insurance or a broader form of producer
23 insurance cannot offer much protection if an area is drifting toward ever less viability.

- 24
25 • Realistic, tough, and market-based environmental and resource programs are needed.
26 These can be a win-win situation. In the climate scenarios we examined increased
27 yields and lower prices led to a reduction in resource use. In the past, acreage
28 reduction programs took vast tracts of land out of production to boost prices. In the
29 same way, environmentally targeted programs that reduce production, either through
30 land retirement or through other types of constraints on production practices, can
31 offset these climate-induced productivity increases, raise commodity prices, and
32 restore income levels. These programs can, in addition, be overall beneficial for the
33 US if the programs are targeted to generate substantial and real environmental gains.
34 If, as projected in our analysis, use of water and land resources declines because of
35 climate change, it may be more feasible to reallocate resources to environmental and
36 conservation goals. Here, however, we need to keep in mind that our projections are
37 for reduced resource use compared with a reference. If far greater demand for
38 resources occurs for other reasons (demand growth abroad) then we will not see these
39 reductions compared to current levels. Thus, again, climate change is just one of the
40 factors that needs to be considered.
41
- 42 • Finally, a considerable caution is needed in recommending specific technological
43 solutions or directions for agricultural research. A decade ago, the main fear of
44 climate change was drought but in the scenarios we examined precipitation over
45 much of the country increased, reducing the number of irrigated acres and the demand

1 for water. Flooding and excessively wet field conditions may pose a greater threat, at
2 least as now projected. Rather than bet on one scenario or another, a distributed
3 portfolio of research is needed representing a variety of perspectives on how the
4 future might evolve.

5
6
7 The surprising finding in our analysis is that climate change as it affects agriculture may
8 well be beneficial to the US economy through the next century. It will, however, create
9 winners and losers and contribute to dislocation and disruption that imposes costs on
10 localities. That local and regional effects and issues can differ substantially was
11 illustrated in our case studies of the Chesapeake Bay drainage area and the Edwards
12 Aquifer region in Texas. It may well be the case that agriculture or some types of
13 agriculture will become non-viable in some areas under climate change. The truly
14 difficult aspect of adaptation and adjustment is to decide when to make further
15 investments in a particular farming practice or farming region and when conditions have
16 become so adverse that the sensible strategy is to find another line of work.

17